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Early Holocene groundwater table fluctuations in relation to rice domestication in the middle Yangtze River basin, China

Tao Liu [a, b], Yan Liu [a, *], Qianli Sun [a], Yongqiang Zong [c], Brian Finlayson [d], Zhongyuan Chen [a]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China
[b] Hubei Key Laboratory of Regional Development and Environmental Response, Hubei University, Wuhan 430062, China
[c] Department of Earth Sciences, The University of Hong Kong, Hong Kong, China
[d] School of Geography, The University of Melbourne, VIC 3010, Australia

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ABSTRACT

The early Holocene environmental amelioration stimulated the trajectory of Neolithic farming cultures and specific geographic settings played a role in determining the nature of these cultures. Using microfossil evidence, the present study reveals that the fluctuations of the groundwater table substantially influenced rice domestication in the Dongting Lake area of the middle Yangtze River basin in the early Holocene. Our ^{14}C-dated sediment core taken from the Bashidang (BSD) Neolithic site contains evidence that the site was a floodplain prior to human occupation *ca.* 8600 years ago. Poaceae, which contained wild rice (*Oryza* sp.) as indicated by combined pollen and phytolith evidence, and low counts of freshwater algae indicated a moist site condition. The area then gradually evolved into wetlands as the water table rose, in response to the increasing monsoon precipitation during the early Holocene. This favored rice domestication, assisted by firing and clearing, that continued to flourish for several hundred years. Finally, rice domestication declined during the late stage of the Pengtoushan culture, accompanied by evidence of the expansion of wetlands reflecting the effects of a rising groundwater table that had caused the cessation of rice farming at the Bashidang site after *ca.* 8000-7900 cal yr BP. This study shows that there are local effects at particular sites that may differ from the trend at the regional scale, necessitating a careful interpretation of the available evidence.

1. Introduction

The process by which hunter-gatherers were transformed into territorial settlers during the environmental transition from the Last Glacial Maximum (LGM) to the Holocene has been a subject of considerable scientific debate (Chang, 1986; Lu, 1999; Messerli et al., 2000). Various patterns of early human adaptation to environmental changes occurred in different geographic regions in response to the Holocene climate warming, and the accompanying sea level rise and lake level changes (Stanley and Warne, 1993; Magny, 2004). This period is important in China, as it determined the timing, location and processes of rice cultivation and these have been subjected to extensive research (Cultural Relics and Archaeology Institute of Hunan Province, 2006; Gross and Zhao, 2014).

There have been ongoing discussions in the literature about this environmental transition and related development of rice cultivation in China with suggestions that climate warming and increasing monsoon rainfall in the early Holocene would favor the development of wild rice (*Oryza* sp.) (Cultural Relics and Archaeology Institute of Hunan Province, 2006). However, the timing of rice cultivation in different regions was dependent on their diverse physical characteristics. For example, rice farming in the Pearl River delta of southern China (2500-2200 cal yr BP) occurred much later than in the lower Yangtze River basin (7000 cal yr BP), possibly due to more food choices being available in a tropical area than in the more northerly temperate region (Fuller et al., 2009; Zong et al., 2013). The middle Yangtze basin has been widely reported to be the region where rice farming began, as the exploitation of wild rice could have begun as early as 12,000 cal yr BP (Fig. 1) (Higman and Lu, 1998; Zhao, 1998), though some studies suggest that similar early rice farming occurred in the south and southeast areas of

* Corresponding author.
E-mail address: yliu@tongji.edu.cn (Y. Liu).

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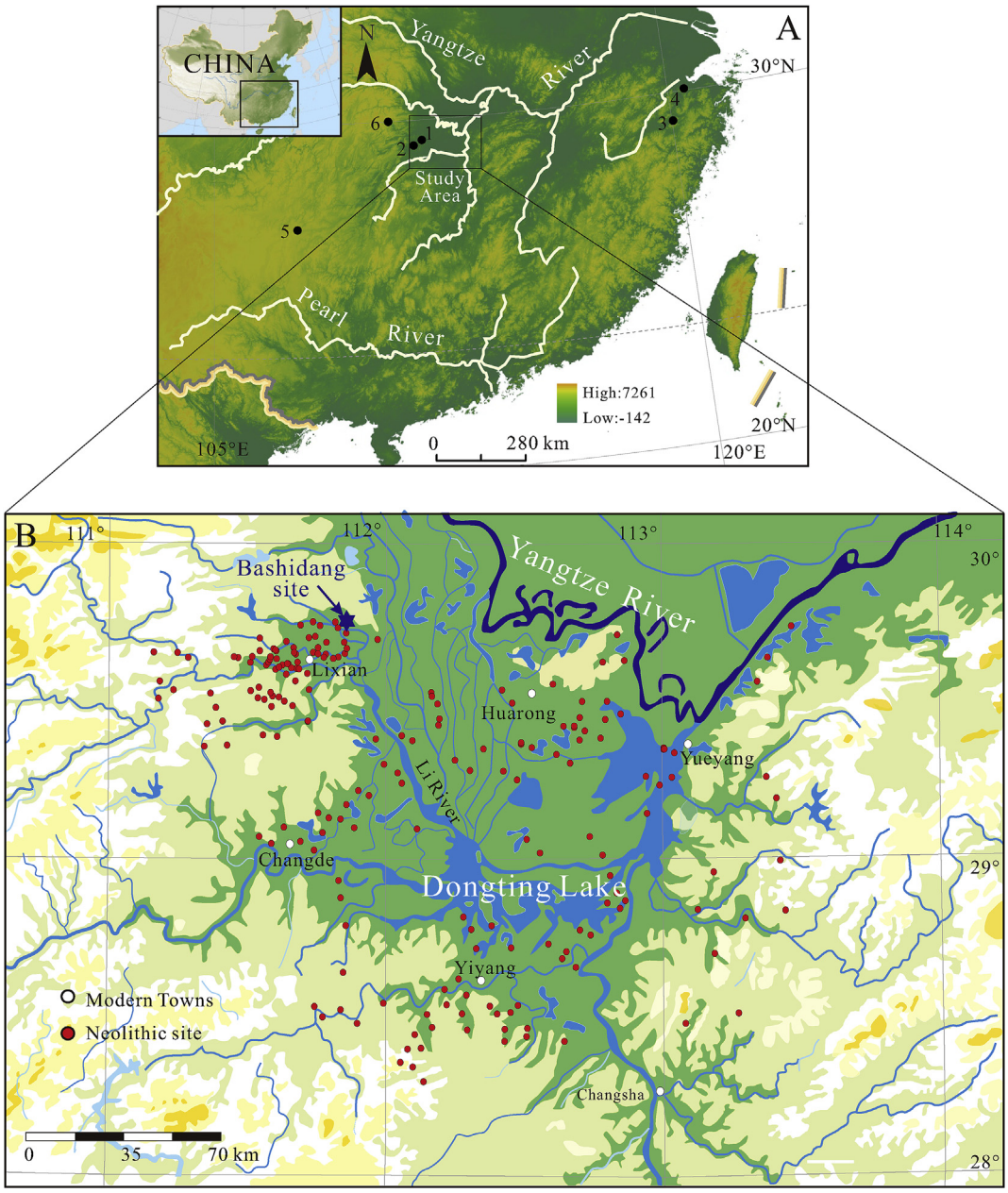

Fig. 1. Location of the study area. **A)** Southeast China, several key sites of early rice farming (before 7000 cal yr BP) are shown - (1) Bashidang; (2) Pengtoushan; (3) Shangshan; (4) Kuahuqiao; also stalagmite records are from (5) Dongge Cave and (6) Heshang Cave. **B)** Dongting Lake basin, showing the location of numerous Neolithic sites, including Bashidang of this study.

China (Fig. 1A) (Huang et al., 2012). However, details of the environmental context of these sites are little known.

The initiation of rice cultivation requires the presence of wild rice and the existence of freshwater wetlands with favorable water thermal conditions (Richerson et al., 2001). It has been shown that favorable environmental settings for rice domestication occurred at widely dispersed sites during the early Holocene environmental amelioration in China (Pei et al., 1998), with many key sites (before 7000 cal yr BP) in various locations in the mid-lower Yangtze River basin having been reported to contain rice remains (Fig. 1A). For instance, the Shangshan site of *ca.* 11,000–8600 cal yr BP, in a mountainous valley south of the Yangtze delta, had some small-scale ponds for freshwater storage apparently facilitated by the warming climate and increasing monsoon rainfall in the early Holocene (Fig. 1A) (Jiang and Liu, 2006). This offered the early foragers the opportunity to farm rice, even under conditions where this may have been transient at particular locations. Rice farming developed more widely on the Yangtze delta *ca.* 8000-7000 years ago, when extensive wetlands became available as the delta was forming. The desalinization of these delta wetlands provided a favorable environmental setting for wild rice to flourish (Zong et al., 2007; Qin et al., 2011; Liu et al., 2016), leading to subsequent rice cultivation and domestication. In contrast, rice pollen and phytoliths (domesticated?) were identified in the Yuchangyan cave site of the middle Yangtze River basin, but the environmental conditions under which it grew are yet to be determined (Zhang and Yuan, 1998). At the Bashidang archaeological site of the Pengtoushan culture (*ca.* 9000-7900 cal yr BP) there have been more rice grain